Brief Report: autistic students read between lines

Article

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Abstract

Students with Autism Spectrum Disorder (ASD) tend to struggle with reading comprehension, often resulting in difficulties with inference generation. While most of the previous research has focused on the product of comprehension, we report a preliminary validation of an experimental reading task in English to measure, by means of eye-movements, the time course of generating consistent and inconsistent inferences during reading. The task was tested with a group of 12 students with ASD (age range: 10-15) who showed accuracy differences between inference and control conditions. Participants spent longer reading in the inconsistent than control condition regarding go past times and second pass times and made more regressions into the target and post-target regions, but these differences were not significant.

Keywords: autism spectrum disorder, eye-movements, reading, inference

Introduction

Reading comprehension difficulties are more common (30-50%) in students with Autism Spectrum Disorder (ASD; Sorenson et al, 2021) than those without (10-15%; Nation & Snowling, 1997), and may be linked to difficulties in inference generation, that is, using information in the text and previous knowledge to understand text meaning that is not explicitly stated (Cain & Oakhill, 1999). Difficulties generating inferences could arise from a central cohesion deficit (Frith, 2003): individuals with ASD may attend to details within a text rather than to large, coherent patterns of information. Alternatively, the poor comprehension profile in ASD may be linked to a core language delay rather than autistic status per se (Lucas & Norbury, 2014). The aim of this study was to explore the time course of inference processing during reading in children and adolescents with ASD using eye movement measures. Tracking a reader's eye movements is an excellent way to monitor their ongoing comprehension of text (Rayner, 2009) and has been shown to be sensitive to differences in reading patterns on passages that do and do not require an inference to be generated (Joseph et al., 2021). We were interested in bridging inferences which serve to establish connections between clauses. For example, in the text "*the window was open so Tom put on his jacket*", the reader must infer that it was cold inside because the open window let in cold air which led Tom to put on his jacket to warm up. According to the validation model of bridging inferences, such inferences are only accepted by the comprehender when validated, both with reference to the cause and outcome, and based on their knowledge about the world (Singer, 1995). In our example, there are just two actions (window opened and jacket put on) and the reader must activate their previous knowledge that open windows can make rooms colder in order to link them as cause and consequence.

In an eye movement study, Micai et al. (2017) examined bridging inferences during reading in a group of children and adolescents with and without ASD, and found that the two groups did not differ in their global comprehension or reading times, but the ASD group showed longer initial reading times on the target word in the inference compared to the literal condition, and looked back more often to the target word (irrespective of inference condition) than the control group. The authors interpreted their findings as showing that initial processing of text does not differ between ASD and non-ASD readers but that ASD readers may have a less-specified situation model which triggers regressions and re-reading behaviours at the point at which an inference is needed. However, Micai et al.'s literal condition required a (small) inference and contained a repeated word, known to affect processing times (Joseph et al., 2021). The present study expanded on previous research by using an inconsistency paradigm to foster inferential processing in specific regions of interest during text reading.

Method

Participants

To recruit participants, local schools and autism societies in south-east England were contacted and data are reported from a final sample of 12 participants with ASD, aged 10 to 15 years. A summary of descriptive data and disaggregated and anonymized data are shown in Online Resource 1 and 2. The descriptive data include the results of a set of standardised tests of reading, oral language and reasoning skills. This wide age range is typical in previous research on reading comprehension in ASD due to recruitment challenges (e.g., 8–14 years in Davidson & Ellis Weismer, 2017). In addition, this age group was chosen to ensure that participants were likely to be fluent word readers but were not yet adult-like in their reading behaviour (as Online Resource 1 and 2 show, their standard scores in word/non word reading accuracy were above 70, values below this threshold correspond to 2 SDs below the mean). Parents and/or teachers of the students confirmed that they had received a formal ASD diagnosis (consensus clinical ICD-10/DSM-5 diagnosis of ASD) and most of them were enrolled in special units for which the ASD diagnosis is mandatory. This study has been conducted in accordance with the Declaration of Helsinki and approved by the University Research Ethics Committee (UREC) of the University of Reading (UK). All participants (children and parents) provided informed consent prior to being included in the study. All participants (children and parents) provided informed consent prior to being included in the study.

Reading task

Participants were asked to complete a text comprehension task (adapted from Joseph et al., 2021) in which they read 30 short texts in English (see Table 1; complete set of texts in Online Resource 3). In the two inference conditions (consistent and inconsistent), readers needed to determine the causal relationship between the final two sentences. The content of the second sentence was manipulated in order to be consistent or inconsistent with the target word in the third sentence. In the control condition, the target word followed a neutral context so no inference was needed. Note that the target word (*umbrella*) was identical across conditions to eliminate any potential effects of word length and frequency. The post-target (spillover) region consisted of the one or two words following the target word. As Online Resource 4 shows, pre-target regions (second sentence) and post target regions were similar regarding average word frequency across conditions but they differed in length (number of words). To control for the effect of length, number of words was introduced as covariate in the subsequent analyses.

Insert Table 1 around here

Both comprehension products (i.e., answers to multiple choice questions after reading) and processes (i.e., reading times and regressions on target regions) were measured. Each question had three possible responses: a) correct (in consistent and control conditions); b) incorrect and c) detection of inconsistency (correct in inconsistent condition). The question and responses were identical in the two inference conditions but different in the control condition.

Predictions: comprehension product

It was predicted that children with ASD would make bridging inferences, but these would be harder than the control (no-inference) condition, resulting in lower scores in both inference conditions than the control condition.

Predictions: online processing (eye-movements)

We expected effects of the inference condition only in late eye-movement measures (Rayner, 2009). Consequently, gaze duration (the sum of fixation durations prior to moving to another area, also known as "first pass") was introduced as a control measure, but we did not predict any first pass effects. In line with Micai et al., (2017), we predicted that children with ASD would attempt to make bridging inferences while reading the text, and this would be reflected in longer reading times (go-past time, total fixation time and re-reading time) and more frequent regressions-into and out of the target word and the post-target region as well as longer re-reading time and more frequent regressions-into the pre-target region in the inconsistent inference condition, followed by the consistent inference condition and then the control condition (eye-movement measures are described in full Online Resource 5).

Results

Although our sample was small, we performed preliminary analyses based on what we planned in our pre-registration document (Joseph & Fajardo, 2020; https://doi.org/10.17605/OSF.IO/VM7S6). For reading time measures (Gaze, Gopast, Second pass and Total Time), fixations under 80 ms or above 1200 ms were discarded in line with conventions in the field (e.g., Fajardo et al., 2021; Joseph et al., 2015). In addition, data points more than 2 SDs from participant and condition means were excluded from the analysis. As reading times measures were positively skewed, they were logtransformed in order to approximate a normal distribution. Participants with more than 50% of missing data (two out of 16 participants who completed the experimental task), were removed from the analysis. The remaining missing data were treated as "excluded" so that all other participants could be included in the analyses, that is, we used "case deletion" as missing data handing method (Cheema, 2014).

Generalized linear-mixed-effects models (GLMM) were used to analyse both comprehension accuracy and binary eye-movement measures (regressions in and regression out) and linear-mixed-effects models (LMM) were used to analyse the reading time data. There was only one categorical fixed effect: Inference condition (consistent inference, inconsistent inference, and literal control). Participants and texts (item) were treated as crossed random effects, and random intercepts and slopes were included in the models. As pre- and post-target regions differed in length across conditions, the number of words (centred) was entered as a covariate in the models for reading time measures. It is important to include covariates such as age and language skill as fixed effects but we were not able to do this due to our small sample. However, all data available to the research community in the hope that they can add to our dataset (Online Resource 1 and 2).

Untransformed descriptive data (means and SD per condition, measure and region) are reported in Table 2. Summary statistics for the converging models can be found in Online Resource 6. The t / $\chi 2$ / z, p values reported in this table correspond to the analyses using the log-transformed variables. The emmeans () function in R was used to conduct pairwise comparisons between inference conditions (consistent, inconsistent, control).

Insert Table 2 here

Comprehension product

The effect of inference condition was significant (χ^2 consistent vs. control = 13.653; $p < .001$) with higher accuracy in the control versus the consistent condition ($z = -3.199$; $p = .004$; $d = -.42$) and in the control versus the inconsistent condition ($z = 3.221$; $p = .004$; $d = -.42$). There was no difference between the two inference conditions ($z = 0.029$; $p = .999$; $d = .004$). However, children with ASD did make bridging inferences as their accuracy in both inference conditions was high (88%), albeit significantly lower than in the control condition (99%).

Eye-movement patterns

The effect of inference condition was not significant in any measure in any region except for gaze durations in the post-target region (F = 4.668; p < .01). Contrary to expectations, participants' gaze durations in the post-target region were longer in the control than the inconsistent condition (t = -2.97; p = .001; d=-.25). Neither the difference between the consistent and the control conditions (t = 1.04; p = .552; d=.21) nor between the consistent and inconsistent conditions (t = -2.082; p = .097; d=-.04) were significant. There were no reliable effects in any other measure.

Discussion and conclusions

The aim of this study was to explore the time course of inference processing during reading in children and adolescents with Autism Spectrum Disorder (ASD) by means of eye movement measures. Our paradigm was valid in detecting accuracy differences between inference and control conditions although performance was high in general for our 12 participants with ASD. The descriptive data suggest that participants spent longer reading in the inconsistent than control condition in later measures (go past times and second pass times) and made more regressions into the target and post-target regions although these differences were not significant. The only significant effect of inference condition was in gaze durations in the post-target region in an unexpected direction (longer reading times in the control condition). As integration processes are not observed in first pass measures, we argue that this is an artefact derived from the response option "The text doesn't make sense". It may be that once participants encountered the inconsistent word, they read the rest of sentence more superficially as they already knew the correct answer, unlike in the control and consistent conditions. This artefact, however, demonstrates that participants were noting the inferential inconsistency at an early stage of the text online processing.

Our accuracy and eye-movement results suggest that children with ASD do not have difficulties resolving bridging inferences while reading short paragraphs which is consistent with data from adults with ASD (Howard et al., 2017) and previous research with children with ASD (Micai et al., 2017). Our contribution regarding the Micai et al. (2017) study is that we used a more refined paradigm to ensure that: 1) there was no inference at all required in the control condition; and 2) participants were generating an inference through our inclusion of an inconsistent condition. In addition, we designed the paragraphs such that the target region in consistent, inconsistent and control conditions was identical so no differences could be attributable to lexical or sub-lexical characteristics of the target words. Finally, the pre- and post-target regions were carefully controlled in order to be as similar as possible between conditions. Although we did not detect inference effects in our selected later eye-movement measures, likely due to our small sample size, our paradigm allows the possibility of studying processing differences between different regions of interest between groups of participants. In addition, it should be noted that with a larger sample, age and language skills could be added as covariates and this may reveal a different pattern of effects because, as supported by previous research (e.g., Brock, Norbury, Einav and Nation, 2008; Lucas and Norbury, 2014; Norbury and Nation, 2011), the core language acquisition delay common in ASD rather than autistic status per se, may predict differences in inference making between ASD and typical development groups.

From the point of view of educational practice in school settings, our results challenge the deficit conception of ASD because our students were very accurate in answering inferential comprehension questions after reading short stories. They also tended to spend longer reading the consistent and inconsistent words which were important for the inference processing compared to those in the literal condition. As the scarce previous research on online text processing in children and adults with ASD suggests (Fajardo et al., in press; Howard et. 2017; Micai et al., 2017), the instructional focus should be the way ASD students solve inferences (e.g., more and longer revisits to previous part of the text before answering comprehension questions) and not the output. Future research which uses our paradigm with a larger sample, or aggregated results from different research laboratories, might contribute to our understanding of the diversity in eye-movement pattern of students with ASD, thereby informing curricular adaptations in mainstream classrooms such as giving students longer to complete reading tasks or explicitly asking ASD students to make inferences.

Perhaps the most significant contribution of this paper, however, is to offer our materials, data, and code to other researchers in the field. Having shown that our paradigm is valid and sensitive to small processing differences, we hope that researchers in the fields of autism and reading comprehension will be able to add to our dataset and examine the role of individual differences in language and cognitive ability on the time course of inference generation during reading. It is crucial that researchers in this field work together to enable us to address important questions which can be done only with large datasets.

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Tables

Table 1. Example stimuli for the consistent, inconsistent and control conditions. In each version of the passage the target region is in bold and the post-target region is in italics.

Inference Consistent and Inconsistent	**No inference (control)**
Mr Jones was on his way to a meeting and it was almost 5 o'clock. He looked up at the dark grey clouds in the sky (Inference consistent condition)/He looked up at the clear blue sky without any clouds (Inference inconsistent condition) He put up his **umbrella** *and carried* on walking down the street. Why did Mr. Jones put his umbrella up? a. Because it was going to rain. b. To protect him from the sun. c. The text doesn't make sense.	Mr Jones was on his way to a meeting and it was almost 5 o'clock. He went into the office building and took the lift. He opened his briefcase and his **umbrella** *dropped on* the floor with a clatter. What happened to Mr. Jones's umbrella? a. His umbrella fell to the floor. b. His umbrella was stolen. c. The text doesn't make sense.

Table 2. Means (SD) per inference condition, measure and region (Untransformed descriptive data)

Region	Inference condition	Accuracy (%)	Gaze duration (ms)	Go past time (ms)	Second pass time (ms)	Total Time (ms)	Proportion Regressions in	Proportion Regressions out
Target	consistent	88 (33)	295 (162)	399 (332)	386 (255)	392 (217)	0.237 (0.428)	0.247 (0.434)
	inconsistent	88 (33)	282 (155)	442 (412)	471 (424)	475 (416)	0.412 (0.495)	0.278 (0.451)
	control	99 (1)	275 (106)	384 (361)	434 (250)	448 (261)	0.275 (0.449)	0.266 (0.445)
Post-Target	consistent		311 (183)	407 (310)	401 (315)	462 (317)	0.379 (0.487)	0.194 (0.399)
	inconsistent		267 (148)	494 (500)	439 (310)	501 (337)	0.483 (0.503)	0.313 (0.467)
	control		341 (264)	560 (664)	472 (330)	497 (346)	0.477 (0.502)	0.193 (0.398)
Pre-target	consistent				1583 (1373)		0.299 (0.460)	
	inconsistent				1194 (994)		0.475 (0.502)	
	control				1361 (1109)		0.270 (0.446)	